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The Effect of Welding Speed on the Physical and Mechanical Properties of Low Carbon Steel Welded Joints Using TIG Welding Using 2 External Magnetic Fields

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Abstract
The use of external magnetic fields is very influential in TIG (Tungsten Inert Gas) welding because it can disrupt the stability of the electric arc formed between the tungsten electrode and the base metal. Magnetic fields can cause the arc to distort or shift, resulting in uneven and low quality welds. TIG (Tungsten Inert Gas) is a welding method that uses a non-melting tungsten electrode to produce a weld. This study aims to determine the effect of external magnetic field on the quality of TIG welding results. This research uses the TIG (Tungsten Inert Gas) welding process on low carbon steel material with speed variations of 4 mm/s, 6 mm/s, 8 mm/s and 10 mm/s and uses 2 Neodymium type external magnetic fields. Tests carried out on the results of welding joints are Vickers hardness test, micro & macro structure test. The highest hardness test value was obtained in the 4 mm/s welding speed variation using 2 external magnetic fields with a hardness value of 187.388 HVN. Microstructure testing shows that the base metal contains ferrite and pearlite structures. In the HAZ (Heat Affected Zone) area there are ferrite, pearlite and martensite structures. Macro structure testing shows several welding defects, including porosity, imperfect penetration, underfill and irregular surface. The use of two external magnetic fields can affect the results of TIG welding itself, such as deepening the penetration of welding so as to produce a good welding joint. Some things you should pay attention to if you don't want welding defects to occur are paying attention to the distance between the electric arc and the material, and the torch must be parallel to the welding line.

Keywords: External magnetic field, low carbon steel, tensile, TIG welding

1. Introduction

Currently, metal joining techniques in the field of welding have developed rapidly in constructions that use metal raw materials, most metal connections are made by the welding method.. Welding is also widely used for construction work such as in buildings, bridges, piping and automotive. In addition to connection, the welding process can also be used for repairs, for example to fill holes in castings, make coatings on tools, thicken worn parts and other repairs. As we know, there are several types of welding used today. Among others are Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW), Submerged Arc Welding (SAW), Flux Core Arc Welding (FCAW) and Gas Tungsten Arc Welding (GTAW) or commonly called Tungsten Inert Gas (TIG) [1][2].

TIG (Tungsten Inert Gas) is a welding process using an arc flame generated by a fixed electrode made of tungsten [2]. While the enhancing material is made of the same or similar material as the material to be welded and separated from the welding torch. The protective gas used in welding is usually pure gas (99% Argon). TIG welding itself can cover a wide range of welding processes and has a high ability to unite metals, and can also weld in all welding positions with high density. The arc power does not depend on the additive required, so TIG welding can be used to weld a wide range of metals [3][4].

Many TIG welding studies have been conducted to improve the quality of welding results. Researchers have explored several methods, including the addition of an external magnetic field, the use of argon gas, and the incorporation of different types of fillers. The introduction of an external magnetic field, in particular, has been found to have several positive impacts. It can significantly increase the depth of weld penetration, which contributes to the formation of stronger and more durable joints. This enhancement in penetration depth ensures that the welded components can withstand greater stresses and are less likely to fail under load. Furthermore, the use of an external magnetic field helps in minimizing weld defects, such as porosity, cracks, and inclusions. By reducing these imperfections, the overall integrity and performance of the welded structures are improved, resulting in higher quality and more reliable welds. This approach not only enhances the mechanical properties of the welds but also contributes to the longevity and safety of the structures in which they are used [4].

Research conducted by Haikal et al., 2020[5] on the effect of adding external megnets to the TIG welding process, which is applied to blunt joints and this welding process is carried out without additional filler metal (auotogeneus weld). The next research is research conducted by Baskoro, A.S, et al., 2013[5] on the utilization of electromagnetic fields carried out in static and dynamic conditions. Selenoid magnetic placement is around the TIG welding torch. The results of the study showed the effect of electromagnetic effects on making a more stable and smaller arc with deep weld penetration. This welding also uses lower power so as to obtain efficient use of electrical energy and limit higher heating. Based on this background, it is necessary to conduct further research on the effect of external magnetic fields and welding speed on the quality of welding.

2. Methodology

The material used in this study is low carbon steel with a size of 10x10x3 mm. Low carbon steel is often chosen for TIG welding due to its ease of welding which results in a strong joint without significantly altering the microstructure. Its stability during the welding process and affordable cost also make it popular. Its wide availability and adequate strength for most industrial applications make it a versatile and efficient choice [5]. Table 1 shows the composition test results of the material.

Table 1. Composition Test Results

No.	Composition	Rate (%)
1.	Feron (Fe)	96,4
2.	Carbon (C)	0,33
3.	Manganese (Mn)	0,28
4.	Phosporus (P)	0,0018
5.	Sulfur (S)	0,005

The welding process uses a semi-automatic TIG machine. The current used was 80A, argon gas flow rate of 3 l/min, arc length of 2 mm, addition of 2 neodymium magnets on the torch with a distance of 2 mm. The welding speed variations were 4 mm/s, 6 mm/s, 8 mm/s and 10 mm/s. Figure 1 shows the scheme of the magnetization during the welding process. The testing process carried out is the macro, micro and hardness structure of the welded joint. The testing process was carried out at the Mechanical Engineering Laboratory of the Sumatra Institute of Technology.

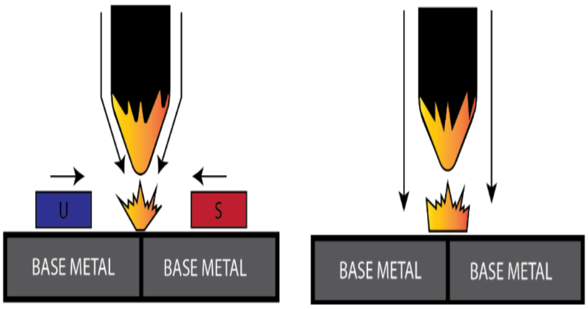


Figure 1. Schematic of Welding Process

3. Result and Discussion

3.1. Heat Input

Heat input is the heat input from electricity that is converted into heat energy. Figure 2 shows a graph of the heat input for this weld. Figure 2 shows the heat input value of TIG welding which shows differences in each speed variation of 4 mm/s, 6 mm/s, 8 mm/s and 10 mm/s. At speed variations of 4 mm/s, 6 mm/s, 8 mm/s and 10 mm/s the heat input value produced continues to decrease, namely 2.64 KJ/mm, 1.76 KJ/mm, 1.32 KJ/mm, and 1.056 KJ/mm. This is because the variation in speed applied affects the heat input exposure received at each speed variation. The lower the speed, the higher the heat input received. The quality of welding results is influenced by the heat energy of welding parameters such as current, voltage and welding speed. Heat input in welding greatly affects the structure and toughness of welding results, especially in low carbon steel materials [6].

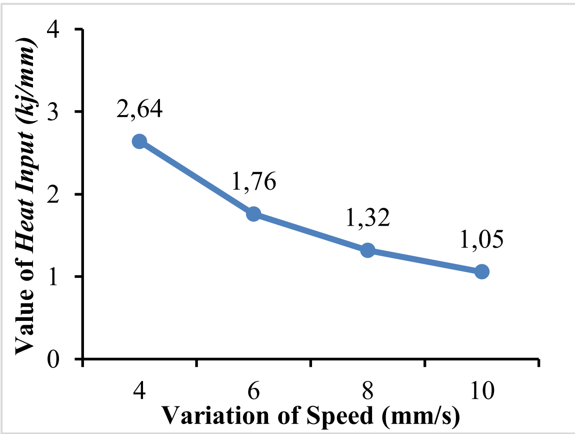
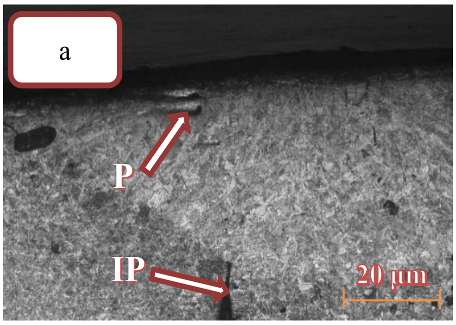


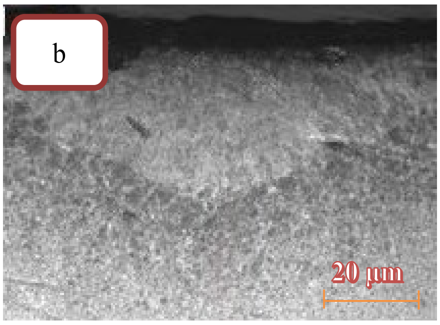
Figure 2. Graph of Heat Input

3.2. Macro Structure

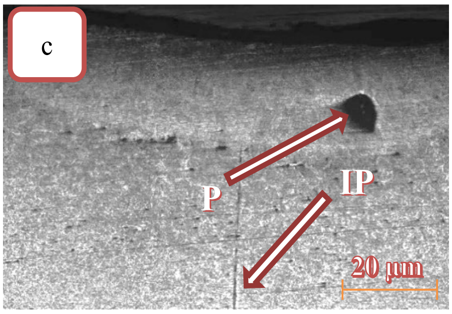
The purpose of this test is to observe and analyze parts of the welding joint and the depth of welding penetration, including the base metal and HAZ (Heat Affected Zone). The results of the macro observation can be seen in Figure 3. The observation results of several welding defects that vary at each welding point obtained from macro structural testing include Porosity, Incomplete Penetration, Underfill, Irregural Surface. Porosity is a type of welding defect in the form of cavities in the metal resulting from the welding process, which is caused by contamination of the molten metal by air bubbles and dirt during the welding process, resulting in air bubbles trapped in the weld joint and forming pores. Porosity can be found in Figures 3.a, 3.c, 3.e. Porosity itself can be avoided by choosing a flux that can bind oxygen (deoxdizer), and ensuring that the welding area or welding material is clean from impurities.



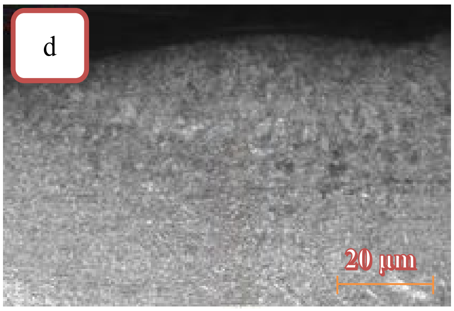
a. Velocity 4 mm/s (without magnet)



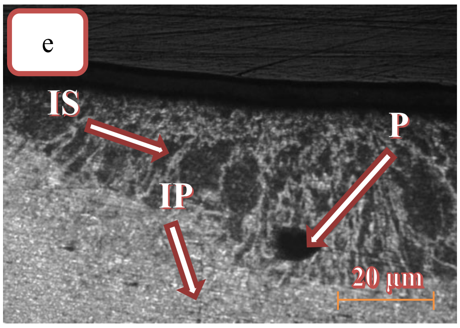
b. Velocity 4 mm/s (2 magnets)



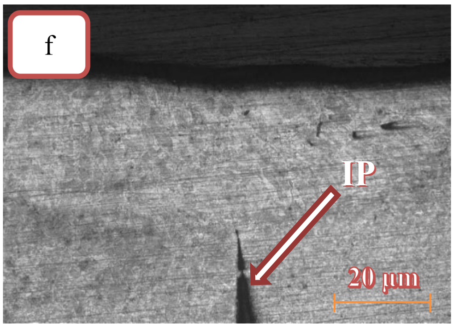
c. Velocity 6 mm/s (without magnet)



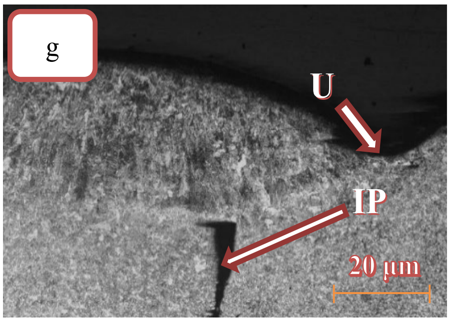
d. Velocity 6 mm/s (2 magnets)



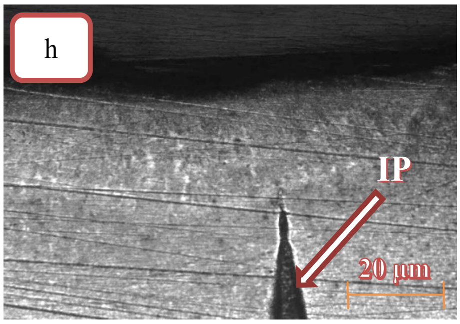
e. Velocity 8 mm/s (without magnet)



f. Velocity 8 mm/s (2 magnets)



g. Velocity 10 mm/s (without magnet)



h. Velocity 10 mm/s (2 magnets)

Figure 3. Macro Structure Testing Results

The next welding defect seen in macro structural testing is Incomplete Penetration. Incomplete Penetration is welding in the form of not penetrating the material from the weld penetration and affecting the results of the mechanical properties of the material itself, which is caused by improper welding speed or too high, welding current that is too low, the angle of the welding wire is wrong, and the distance between the torch and the material is not appropriate or too high. Incomplete Penetration is found in the test specimens in Figure 3.a, 3.c, 3.e, 3.f, 3.g, 3.h.

Incomplete Penetration can be prevented by using the optimal welding current and speed, as well as the correct distance from the torch to the weld material.

The next welding defect encountered in macro structural testing is Underfill. Underfill is a weld defect in the form of a depression in the surface of the specimen. Underfill can occur because the distance between the welding arc and the specimen is too high, the material is dirty, the electrode is damp, and the welding speed is too fast. Underfill can be found in Figure 3.g. Underfill can be minimized or avoided by paying more attention to the distance between the torch and the welding specimen, always ensuring that the material to be welded has no damage and corrosion, and paying attention to the right welding speed.

The last type of weld defect found during macro structural testing is irregular surface. Irregural surface itself can be defined as a welding defect in the form of welding surface conditions that have changes in both thickness and welding surface. Welding results that have an irregular surface can be seen in Figure 3.f. Irregural surface can be minimized by using the right current not too high, as well as the right speed and setting the distance between the right torch [7][8]. The speed variation used in the TIG welding process using 2 external magnets and not using magnets shows that low speed and the right current can increase the depth of welding penetration. The penetration depth graph is shown in Figure 4.

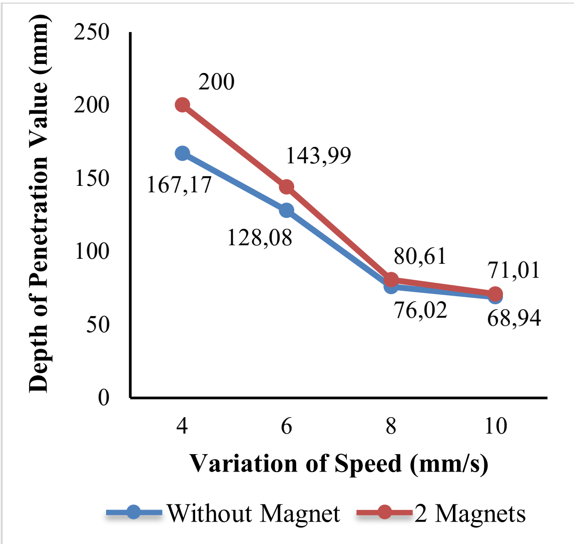


Figure 4. Depth of Penetration Graph

From the results of the macro structure testing above, we can find out about the effect of the welding process without magnets and with the use of external magnets. The welding results shown in Figures 3.a and 3.c of the welding process with speeds of 4 mm/s and 6 mm/s without using magnets experience porosity and Incomplate Penetration welding defects and have a penetration depth of 167.17 mm and 128.08 mm. Whereas at speeds of 4 mm/s and 6 mm/s with the use of 2 external magnetic fields there is no porosity defect in the welding results and welding penetration as deep as 200.00 mm and 143.99 mm [9]. This shows that the use of 2 external magnetic fields on welding has the effect of arranging the welding contours more regularly and reducing porosity and making focused welding penetration which makes the input head obtained more optimal [10][11].

Macro structural testing shown in Figure 3.e welding process without the use of magnets occurs welding defects in the form of Incomplate Penetration, porosity and Irregular Surface and has a penetration depth value of 76.02 mm while Figure 3.f welding process using 2 external magnets only experiences welding defects in the form of

Incomplate Pentration which results in not penetrating the base metal in the welding process and has a higher penetration depth value of 80.61 mm. This shows that the use of two external magnetic fields in welding can control the thickness of the surface and weld contours and increase the depth of welding penetration.

Macro structural testing addressed by Figure 3.g with a speed of 10 mm/s and without the use of external magnets experienced incomplate penetration and underfill welding defects and had a welding penetration depth value of 68.94 mm while Figure 3.h welding results with a speed of 10 mm/s using 2 external magnets only experienced incomplate penetration and had a deeper penetration depth value of 71.01 mm. These results show that the use of magnets at a speed of 10 mm/s can reduce welding defects, but at a speed of 10 mm/s there is a lack of welding penetration due to high speed [12][13].

3.3. Micro Structure

This test data is used as a reference in the process of microstructure testing and hardness testing. The visual results of micro testing on low carbon steel TIG welded joints can be seen in Figure 5 and Figure 6.

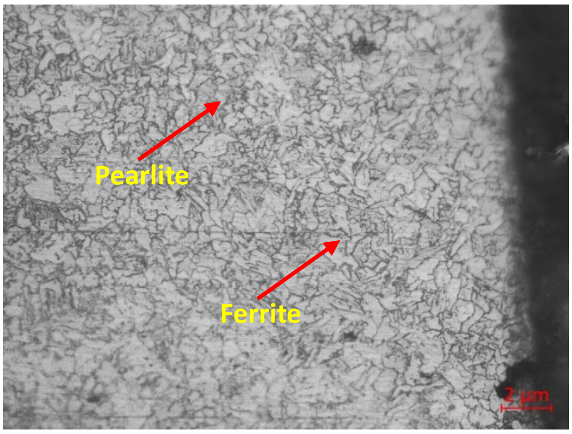
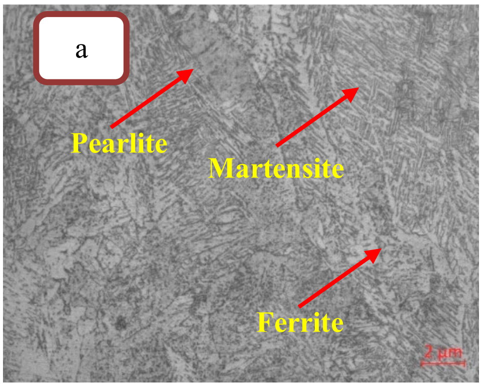


Figure 5. Microstructure of Base Metal

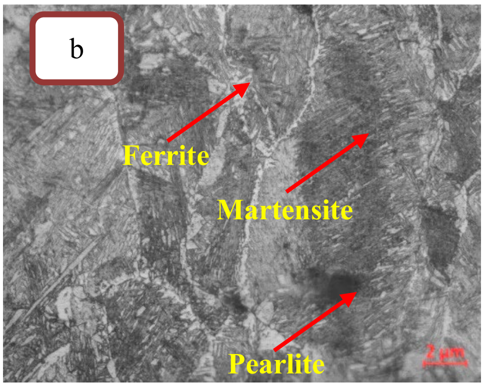
. Low carbon steel has a basic structure composed of ferrite phase. Ferrite is a type of solid solution derived from iron alloy carbon with a composition of 0.02% when the temperature reaches 727ºC. Ferrite also has soft and magnetic properties. The ferrite content is influenced by the heat treatment given, especially in low carbon steel, the higher the heat treatment given, the lower the ferrite content in the material [14][15].

Microstructure testing in the HAZ (Heat Affected Zone) section has begun to experience phase changes and has new structures, namely bainite, pearlite and martensite. Bainite itself is a phase structure that is less stable and is obtained at temperatures lower than the phase transformation temperature to pearlite and higher than the phase transformation to the martensite phase structure. Martensite is a type of carbon solid solution that results from the formation of iron with a rapid cooling stage. Martensite itself has hard and brittle characteristics produced by the carbon composition of the iron itself. The phase structure of welding results without the use of 2 external magnetic fields and the use of 2 external magnetic fields at a speed of 4 mm/s the phase structure formed is ferrite, pearlite, and martensite. At a speed of 4 mm/s with the use of 2 external magnetic fields, the martensite structure formed is much tighter and tends to be dark in color.

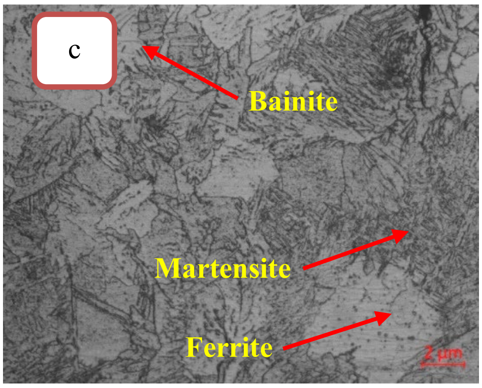
In testing the microstructure of welding results without the use of 2 external magnetic fields at a speed of 6 mm/s, the phase structures formed are ferrite, bainite and martensite phases. However, testing the microstructure of welding results with the use of 2 external magnetic fields at a speed of 6 mm/s, the phase structure formed is ferrite and martensite phases.



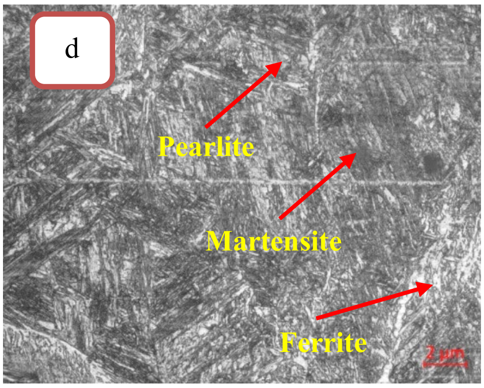
a. Velocity 4 mm/s



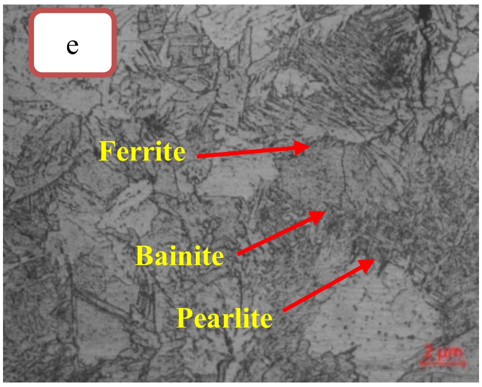
b. Velocity 4 mm/s + magnet



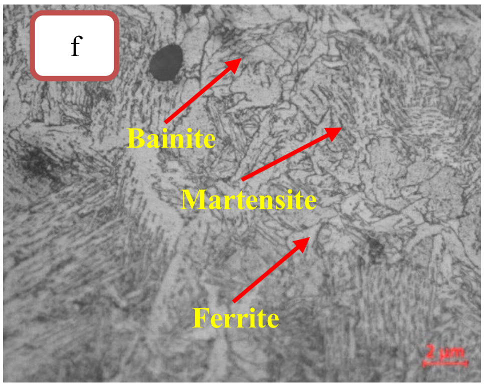
c. Velocity 6 mm/s



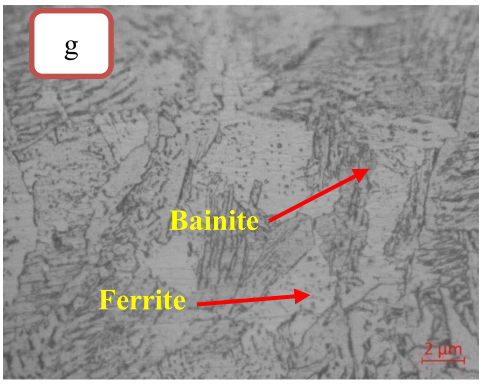
d. Velocity 6 mm/s + magnet



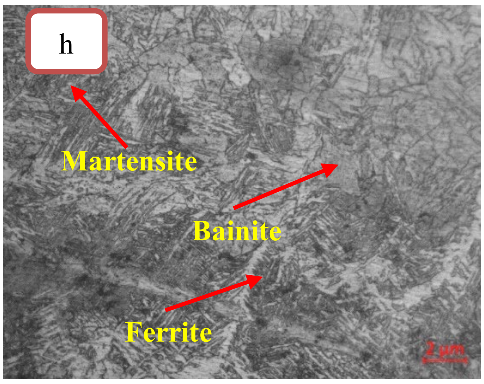
e. Velocity 8 mm/s



f. Velocity 8 mm/s + magnet



g. Velocity 10 mm/s



h. Velocity 10 mm/s + magnet

Figure 6. Microstructure of HAZ Area

While the phase structure of the microstructure test results at speeds of 8 mm/s & 10 mm/s without the use of 2 external magnetic fields, the phases formed are only ferrite and bainite, where at speeds of 8 mm/s and 10 mm/s welding using 2 external magnetic fields the phases formed are ferrite, bainite and martensite. Although at this speed the martensite structure formed changes in density and is slightly brighter [16]. This is due to the influence of high current and speed and the factor of using 2 external magnetic fields in the welding process.

Microstructure testing that has been carried out shows that the use of a speed of 4 mm/s with a current of 80 A and the use of 2 external magnetic fields greatly affects changes in the microstructure content of low carbon steel. The lower the speed treated and the use of 2 external magnetic fields make the results of low carbon steel welding have 3 phase structures namely ferrite, pearlite and martensite, but are more dominated by martensite structures which have harder properties than the original properties of the meterial itself [17].

3.4. Hardness

Hardness testing using Zwickroell Hardness Test Machine with Vickers hardness testing method. It can be concluded that the value obtained from both tests has decreased both from the value or graph, in each speed variation. TIG welding using 2 external magnets has a higher hardness value than TIG welding without using magnets.

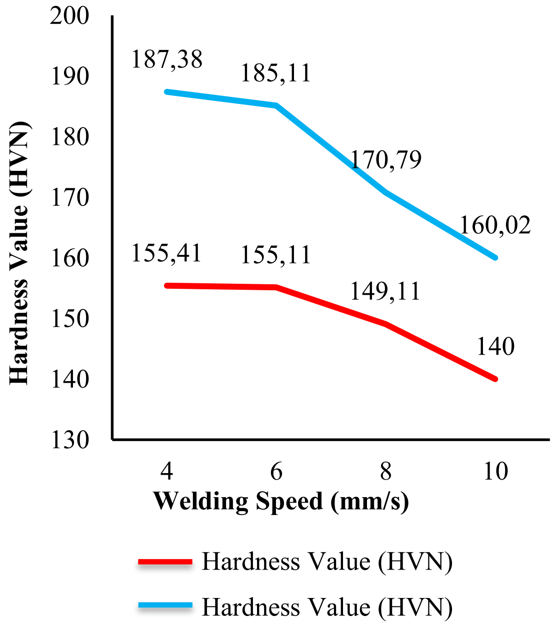


Figure 7. Hardness Value Graph

At a speed of 4 mm/s has a hardness value with a welded joint of 187.388 HVN, while welding without using a magnet with a speed variation of 4 mm/s only has a hardness value of 155.416 HVN. This can also be seen from the results of microstructure testing at speed variations of 4 mm/s and 6 mm/s where the dominating structure is the martensite phase structure [18][8]. Martensite is a phase structure that has hard and brittle properties. The results of this hardness test prove that the use of 2 external magnetic fields in the welding process and low speed can provide greater penetration in the metal melting of the test specimen itself, so as to increase the hardness value of the welding joint and affect the structure and toughness of the test material itself [19][3].

4. Conclusion

Visual results of macro structure testing show that welding using 2 external magnetic fields affects welding defects and HAZ (Heat Affected Zone) width. The use of 2 external magnetic fields and low speed results in deeper penetration and a wider HAZ compared to welding without the use of magnets. Furthermore, the effect of using 2 external magnetic fields in the welding process with low speed on the microstructure of TIG welded joints produces a martensite phase structure. Low speed variations in the welding process produce ferrite and pearlite phase structures that are increasingly reduced compared to the martensite phase structure which is increasingly spread and denser, especially at a speed of 4 mm/s. And finally, hardness testing of TIG welded joints with the use of 2 external magnetic fields shows, with low speed variations and the use of 2 external magnetic fields during the welding process produces maximum heat so that it affects the properties of the material. So that it can increase the hardness value of the material from the previous one.

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